

# REPORT DOCUMENTATION PAGE

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12 a. DISTRIBUTION / AVAILABILITY STATEMENT  Approved for public release; distribution unlimited.				12 b. DISTRIBUTION CODE	
13. ABSTRACT (Maximum 200 words)  CY2002 was the final year of this 6-yr project during which the Boise Hydrogeophysical Research Site (BHRS) was established as a field-scale test facility to support development of methods for using indirect (abundant, minimally-invasive, inexpensive) geophysical information to supplement direct (sparse, invasive, expensive) hydrogeologic information. The BHRS consists of 18 wells emplaced in 20-m-thick coarse fluvial deposits that may be divided into five stratigraphic units with layered and patchy heterogeneity at three scales. Wells are located and constructed to support a wide-variety of hydrologic and geophysical tests. State-of-the-practice and new methods and instrumentation have been used to determine the three-dimensional distribution of geologic, hydrologic and geophysical parameters, including: core analysis; borehole geophysical logging; single-well permeability, seismic, and radar profiling; crosswell seismic and radar tomography; multiwell hydraulic tomography; dense grids of transient electromagnetic soundings and radar reflection profiles; and a tracer/time-lapse radar imaging test. Additional results of note include: development of a general form of the variogram function to quantify multiscale, multifacies spatial structure; demonstration of Voigt-solid model for seismic SH-wave behavior to yield damping in addition to stiffness parameters; development of hydraulic tomography method for 3D permeability distribution; applying and developing new theory to model time-lapse attenuation differences for radar tomographic imaging of a tracer test (analogous to high TDS contaminant plume). Additional findings and developments are given in the report.					
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## REPORT DOCUMENTATION PAGE (SF298)

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#### I. STATEMENT OF THE PROBLEM STUDIED

It is widely acknowledged that: (a) hydraulic conductivity (K) is the most significant aquifer parameter for quantitatively describing or modeling groundwater flow and contaminant transport, and for designing remediation systems; (b) K commonly has a heterogeneous 3D distribution that cannot practically be determined directly or predicted with confidence from well tests or samples; and (c) the most promising means for supplementing direct information is with "soft," or indirect, geophysical data. A field-scale test facility (research wellfield) in a natural heterogeneous aquifer (e.g., coarse unconfined fluvial aquifer) is needed to support development of methods for accurately estimating 3D distributions of K by supplementing hydrologic data (direct but sparse, expensive, and invasive) with geophysical data (indirect but abundant, inexpensive, and non- or minimally-invasive). Such a research wellfield must support a wide variety of hydrologic, geophysical, and combined hydrologic and geophysical testing for thorough characterization in individual wells, cross-well, and multiwell testing configurations. State-of-the-practice and new field methods, instrumentation, and models must be employed and/or developed to acquire high-quality data to generate "known" 3D distributions of geologic, hydrologic, and geophysical parameters (i.e., establish a "control volume") within the research wellfield (i.e., "test cell" within the control volume having known parameter distributions). Relationships between geophysical and hydrologic parameters must be developed (i.e., from measurements of comparable scale in coincident space at the research wellfield) to support joint inversion of one or several types of geophysical information with hydrologic and geologic information to accurately estimate 3D K distribution. In addition to providing the means for developing field and modeling methods to supplement hydrologic and geologic information with geophysical information to estimate 3D K distributions in heterogeneous aquifers, a fully characterized field-scale test facility (control volume and test cell) also will be a unique resource available to the scientific community for basic and applied research in hydrologic and geophysical disciplines.

#### II. SUMMARY OF THE MOST IMPORTANT RESULTS

##### II.A. Development of field-scale test facility: Boise Hydrogeophysical Research Site

The Boise Hydrogeophysical Research Site (BHRS) was installed in 1997-1998 with 18 wells cored, drilled, and constructed on a gravel bar adjacent to the Boise River 15 km from downtown Boise, Idaho. This installation included: 13 wells in the central area for detailed characterization and testing; >83% core recovery from ~20-m-thick coarse, unconsolidated fluvial deposits; minimal disturbance to adjacent formation; construction with materials to provide access to full saturated thickness and to minimize interference with geophysical measurements (e.g., radar, seismic, electrical).

A road was built to access the BHRS which is part of an undeveloped natural area owned by the Idaho Transportation Department (ITD). Long-term renewable permits with ITD, the U.S. Bureau of Reclamation, and Ada County allow prescribed access to and development of the site. Operation of dams on the Boise River nearby upstream of the BHRS provide predictable, stable boundary conditions for field tests at the BHRS. Field tests are not conducted between November 15 and March 15 to honor permit conditions that protect wintering bald eagles along the Boise River.

The hydrogeological framework at the BHRS is highly favorable for the development of methods to determine 3D heterogeneous distributions of hydrologic and geophysical parameters and to formally relate them to the 3D K distribution. The 20-m-thick coarse fluvial sedimentary system hosts a 16-18-m-thick unconfined aquifer above a continuous clay. The clay provides a basal no-flow boundary to the aquifer and a geological material with highly contrasting properties to the coarse sediments for easy location with a variety of geophysical methods. Results from a variety of geologic and geophysical methods indicate the presence of three scales of sedimentary organization (architecture) including layers and patches or lenses. That is, the BHRS contains 3D heterogeneity for study with both gradual and abrupt, and lateral and vertical variation at three size scales.

##### II.B. Thorough characterization and importance of porosity as a geologic, hydrologic, and geophysical parameter

Porosity is easily and inexpensively measured in wells with the neutron geophysical logging tool. Systematic porosity distributions (i.e., continuous bodies with characteristic mean and variance) allow subdivision of the deposits into hydrostratigraphic units and subunits where direct methods for geologic analysis are not available. That is, trenching was not possible at the BHRS and observation of sedimentary structures or units in core was not possible because of the large size of framework grains (commonly cobble size) and sedimentary structures compared with the size of the core barrel (<7 cm). Porosity stratigraphic determinations from well logs have subsequently been confirmed with geostatistics, statistical analysis of core (i.e., with lithotype occurrence distributions and transition probabilities), hydrologic measurements (single well, multiwell, and tracer test), radar measurements (VRPs, level runs, tomography including reflections in crosswell data, and reflection profiles), and seismic measurements (VSPs and tomography including reflections in crosswell data). Also,

porosity is a significant parameter in functional or petrophysical relationships between K and other measurements such as electrical conductivity, grain-size distributions, and parameters related to radar and seismic SH-wave measurements. This importance of porosity as an indicator of stratigraphy and link to geophysical parameters and to K suggests that work toward estimating 3D K distributions may also proceed by first estimating a 3D porosity distribution with geophysical methods and then relating the porosity distribution to K, as well as by determining relationships to K for the variety of geophysical measurements that may be available.

## **II.C. Heterogeneity, hierarchical geostatistics, general form of the variogram function**

Quantifying heterogeneous spatial distributions of hydraulic parameters has been an area of vigorous research activity. This project has made the following two contributions in this area: (1) providing a quantitative explanation for the often-seen occurrence of greater sills perpendicular to layering versus parallel to layering for layered systems; and (2) developing a general form of the variogram function for continuous data that fully accounts for spatial correlation of multifacies systems at any number of length scales, in any direction, and for either stationary or non-stationary systems.

## **II.D. Importance of damping in addition to stiffness for seismic SH-waves and relationship to hydraulic parameters**

The Voigt model for soil particle motion includes damping in addition to stiffness (elasticity). This model better explains the observed velocity dispersion and amplitude attenuation in vertical seismic profiles with SH-waves at the BHRS (and elsewhere in unconsolidated granular media). Subpopulations of stiffness and damping coefficients from VSP profiles correspond well to porosity stratigraphy at the BHRS. Preliminary investigation suggests a functional relationship may exist between damping and K based on theory and measurement.

## **II.E. Well-bore skin analysis and modeling**

II.E.1 Even though mineral solids were not used during the drilling of wells at the BHRS and formation collapse rather than sand or gravel pack was used at well completion, well-bore skin effects (increased drawdown at pumping wells) were recognized at the BHRS during pumping tests early in the development of the site. Understanding well-bore skin is important for determining accurate K values. Analysis of a variety of information as well as laboratory and modeling experiments indicate that the skin is due to invasion of sand into screen slots - and hence is not a removable feature. We have added the condition of skin at an observation well to the available analytical solution for well-bore skin at a pumping well, and we have also added the capability to model varying pumping rate at very early time (as generally is the case at the start of a pumping test) because well-bore skin effects occur at early time in observation wells that are close or relatively close to the pumping well. New technology associated with fiber-optic transducers used in hydraulic tomography (see II.F below) allow synchronization of measurements at time zero and measurement of head changes and pumping rates at very short time intervals so well-bore skin analysis is possible. Initial results are favorable and analysis of tests for the central BHRS well-field is underway.

II.E.2 Well-bore skin analysis is more than an academic curiosity because both high-resolution measurements of K in boreholes with a flowmeter and 3D estimates of K with hydraulic tomography (see II.F below) assume perfect hydraulic communication between the borehole and the formation. The presence of skin adds a non-linear, K-in-series effect which will cause error unless skin is included in the analysis. To support this analysis, modeling capabilities for in-well flow budget accounting and for lateral variations in the radial flow configuration (i.e., RADMOD) have been added for use in MODFLOW.

## **II.F. Hydraulic tomography: field-scale hydrologic testing method for estimating 3D K**

We have developed a hydraulic tomography method to collect drawdown data in multiple zones isolated by packers in multiple observation wells surrounding a well which is pumped successively for short time intervals from a series of zones isolated by packers. We use prototype high-resolution fiber-optic transducers and customized software developed in an iterative process with much feedback to a commercial vendor. In addition to the high resolution and fast sampling rate, the fiber-optic transducers have a small diameter and are linked to supporting electronics through small-diameter cables which permit threading through small-diameter tubing for rapid deployment and relatively easy zone isolation for many zones per well - without requiring permanently dedicated zones in wells. We are testing inversion methods for the transient 3D, multizone, multiple observation well, multiple test problem. We are proceeding based on recent work in the petroleum literature that demonstrates such problems are tractable. Results from early modeling efforts are promising.

## **II.G. Tracer/Time-Lapse Radar Imaging Test**

In 2001 we conducted a combined hydrologic-geophysical test to collect data from a conventional tracer test as well as from a new method for tracking solute plume movement. We obtained detailed information on distribution of concentration changes in space and time with geophysical imaging of differences over time in tomograms in several planes through the plume. Time-lapse imaging could be a valuable in-situ method for monitoring and for developing information that will improve estimations of 3D K distribution. New log-through packer-and-port technology to allow simultaneous sampling for water chemistry or head change from isolated zones while also running continuous geophysical logging through the well

(i.e., tomographic data collection in this case) was developed for this test in collaboration with researchers at Michigan State University. New theory for attenuation differencing and application of recent theory are being used to generate attenuation difference tomograms. Attenuation differences correlate well with observed measured changes in water chemistry at a highly-resolved (20-zone) control well in cross and longitudinal image planes; efforts are underway to develop a quantitative functional relationship between radar attenuation and conductivity to extend the results to zones and planes that do not contain the calibration well. Flow and transport modeling of the tracer test is in progress. Static and dynamic (time-lapse) geophysical information will be used to improve the estimate of 3D K distribution from this test.

### **III. LISTING OF ALL PUBLICATIONS, THESES, AND TECHNICAL REPORTS SUPPORTED UNDER THIS GRANT**

#### **III.A.1 PEER-REVIEWED PUBLICATIONS (PUBLISHED AND IN REVIEW)**

Barrash, W. and Clemo, T., 2002, Hierarchical geostatistics and multifacies systems: Boise Hydrogeophysical Research Site, Boise, Idaho: Water Resources Research, v. 38, no. 10, 1196, doi:10.1029/2002WR001436, 2002.

Clement, W.P., in review, Choosing the optimal model dimension based on Akaike's information and related criteria: submitted to Geophysics.

Clement, W.P. and Knoll, M.D., in review, Velocity and porosity inversion of vertical radar profiles: submitted to Geophysics.

Michaels, P., 1998, In situ determination of soil stiffness and damping: Journal of Geotechnical and Geoenvironmental Engineering, v. 124, no. 8, p. 709-719.

Michaels, P., 2001, Use of principal component analysis to determine down-hole tool orientation and enhance SH-waves: Journal of Environmental and Engineering Geophysics, v. 6, no. 4, p. 175-183.

Michaels, P. and Barrash, W., in review, Determination of soil permeability from joint inversion of wave dispersion and attenuation: submitted to Journal of Geotechnical and Geoenvironmental Engineering.

Tronicke, J., Holliger, K., Barrash, W., and Knoll, M.D., in review, Multivariate analysis of crosshole georadar velocity and attenuation tomograms for aquifer zonation: submitted to Water Resources Research.

#### **III.A.2 PEER-REVIEWED PUBLICATIONS (IN REVISION AND IN PREPARATION TO BE SUBMITTED IN 2003)**

Barrash, W. and Reboulet, E.C., in revision, Significance of porosity for stratigraphy and textural composition in subsurface coarse fluvial deposits, Boise Hydrogeophysical Research Site: to be resubmitted to Geological Society of America Bulletin.

Barrash, W., Clemo, T., and Johnson, T.C., in prep., Modeling well-bore skin effects in pumping and observation wells: to be submitted to Ground Water.

Hyndman, D.W., Barrash, W., and Palazzolo, T., in prep., New multilevel monitoring system for simultaneous single-well or crosswell geophysical monitoring: to be submitted to Ground Water Monitoring and Remediation.

Michaels, P., in prep., On the identification of wavefields recorded in a shallow multicomponent vertical seismic profile: to be submitted to Journal of Geotechnical and Geoenvironmental Engineering or to Geophysics.

Oldenborger, G.A., Knoll, M.D., and Barrash, W., in prep., Geostatistical structure of ground-penetrating radar data: to be submitted to Water Resources Research

#### **III.B CONFERENCE PROCEEDINGS PAPERS**

Barrash, W. and Clemo, T., 2000, Hierarchical geostatistics of porosity derived from neutron logs at the Boise Hydrogeophysical Research Site, Boise, Idaho: Proceedings of TraM'2000, Liege, Belgium, May 23-26, 2000, IAHS Publ. no. 262, p. 333-338.

Barrash, W. and Knoll, M.D., 1998, Design of research wellfield for calibrating geophysical methods against hydrologic parameters: Proceedings of the 1998 Conference on Hazardous Waste Research, May 18-21, 1998, Snowbird, UT, Great Plains/Rocky Mountain Hazardous Substance Research Center, Kansas State University, p. 296-318.

Barrash, W., Clemo, T., and Knoll, M.D., 1999, Boise Hydrogeophysical Research Site (BHRS): Objectives, design, initial geostatistical results: Proceedings of SAGEEP99, The Symposium on the Application of Geophysics to Engineering and Environmental Problems, March 14-18, 1999, Oakland, CA, p. 389-398.

Barrash, W., Knoll, M.D., Hyndman, D.W., Clemo, T., Reboulet, E.C., and Hausrath, E.M., in press, Tracer/Time-Lapse Radar Imaging Test at the Boise Hydrogeophysical Research Site: Proceedings of SAGEEP03, The Symposium on the Application of Geophysics to Engineering and Environmental Problems, April 6-10, 2003, San Antonio, TX.

Clement, W. P. and M. D. Knoll, 2001, A comparison of vertical and horizontal GPR velocity estimates in alluvial sediments, SAGEEP2001, GP2-4.

Clement, W.P., Liberty, L.M., and Knoll, M.D., 1999, Reverse VSPs and crosshole seismic tomography while coring: Proceedings of SAGEEP99, The Symposium on the Application of Geophysics to Engineering and Environmental Problems, March 14-18, 1999, Oakland, CA, p. 713-722.

Clement, W.P. and Knoll, M.D., 2000, Tomographic inversion of crosshole radar data: Confidence in results: Proceedings of SAGEEP00, The Symposium on the Application of Geophysics to Engineering and Environmental Problems, February, 2000, Arlington, VA, p. 553-562.

Clement, W.P., M.D. Knoll, L.M. Liberty, P.R. Donaldson, P. Michaels, W. Barrash, and J.R. Pelton, 1999, Geophysical surveys across the Boise Hydrogeophysical Research Site to determine geophysical parameters of a shallow, alluvial aquifer: Proceedings of SAGEEP99, The Symposium on the Application of Geophysics to Engineering and Environmental Problems, March 18-21, Oakland, CA, p. 399-408.

Goldstein, S.E., Johnson, T.C., Knoll, M.D., Barrash, W., and Clement, W.P., in press, Borehole radar attenuation tomography during the Tracer/Time-Lapse Test at the Boise Hydrogeophysical Research Site: Proceedings of SAGEEP03, The Symposium on the Application of Geophysics to Engineering and Environmental Problems, April 6-10, 2003, San Antonio, TX.

Knoll, M.D. and Clement, W.P., 1999, Vertical radar profiling to determine dielectric constant, water content and porosity values at well locations: Proceedings of SAGEEP99, The Symposium on the Application of Geophysics to Engineering and Environmental Problems, March 14-18, 1999, Oakland, CA, p. 821-830.

Liberty, L.M., Clement, W.P., and Knoll, M.D., 1999, Surface and borehole seismic characterization of the Boise Hydrogeophysical Research Site: Proceedings of SAGEEP99, The Symposium on the Application of Geophysics to Engineering and Environmental Problems, March 14-18, 1999, Oakland, CA, p. 723-732.

Liberty, L.M., Clement, W.P., and Knoll, M.D., 2000, Crosswell seismic reflection imaging of a shallow cobble-and-sand aquifer: An example from the Boise Hydrogeophysical Research Site: Proceedings of SAGEEP00, The Symposium on the Application of Geophysics to Engineering and Environmental Problems, February, 2000, Arlington, VA, p. 545-552.

Liberty, L., Wood, S., and Barrash, W., 2001, Seismic reflection imaging of hydrostratigraphic facies in Boise: A tale of three scales: 71st Annual Meeting., Society of Exploration Geophysicists, p.1393-1396.

Moret, G., Clement, W.P., and Knoll, M.D., 2002, Curved-ray travelt ime inversion of shallow vertical seismic profiles: Society of Exploration Geophysicists International Exposition and 72nd Annual Meeting, Salt Lake City, UT.

Peretti, W.R., Knoll, M.D., Clement, W.P., and Barrash, W., 1999, 3-D GPR imaging of complex fluvial stratigraphy at the Boise Hydrogeophysical Research Site: Proceedings of SAGEEP99, The Symposium on the Application of Geophysics to Engineering and Environmental Problems, March 14-18, 1999, Oakland, CA, p. 555-564.

Peterson, J.E., Jr., Majer, E.L., and Knoll, M.D., 1999, Hydrogeologic property estimation using tomographic data at the Boise Hydrogeophysical Research Site: Proceedings of SAGEEP99, The Symposium on the Application of Geophysics to Engineering and Environmental Problems, March 14-18, 1999, Oakland, CA, p. 629-638.

### **III.C ABSTRACTS (PAPERS PRESENTED AT MEETINGS BUT NOT PUBLISHED IN CONFERENCE PROCEEDINGS)**

Barrash, W. and Clemo, T., 1999, Hierarchical geostatistics of porosity derived from neutron logs at the Boise Hydrogeophysical Research Site, Boise, Idaho (abs.): Geological Society of America Annual Meeting, October 25-29, 1999, Denver, CO, Abstracts with Programs, v. 31, no. 7, p. A149.

Barrash, W. and Clemo, T., 2000, Hierarchical geostatistics, multifacies systems, and stationarity: Boise Hydrogeophysical Research Site (abs.): Program and Abstracts, SEPM/IAS Research Conference on Hydrogeology of Sedimentary Aquifers, Santa Fe, NM, Sept. 24-27, 2000, p. 14.

Barrash, W. and Knoll, M.D., 1997, Research wellfield for calibrating geophysical measurements against hydrologic parameters (abs.): Fall AGU Meeting, Dec. 8-12, 1997, San Francisco, CA, EOS, v. 78, no. 46, p. F319.

Barrash, W. and Knoll, M.D., 1999, Boise Hydrogeophysical Research Site (abs.): Geological Society of America 51st Annual Meeting Rocky Mountain Section, Abstracts with Programs, v. 31, no. 4, p. A2.

Barrash, W., Knoll, M.D., Clement, W.P., Clemo, T., and Michaels, P., 2002, Determining the three-dimensional distribution of permeability in a heterogeneous fluvial aquifer with hydrologic and geophysical methods, Boise Hydrogeophysical Research Site (abs.): Fall AGU Meeting, December 6-10, 2002, San Francisco, CA, EOS, v. 83, no. 47, p. F461.

Clement, W.P., Liberty, L.M., and Barrash, W., 2001, Using cross-hole GPR reflections to improve tomographic imaging and hydrogeologic interpretation (abs.) Geological Society of America Annual Meeting, November 1-10, 2001, Boston, MA, Abstracts with Programs, v. 33, no. 6, p. A45.

Clement, W.P., Liberty, L.M., Knoll, M.D., and Barrash, W., 1999, Imaging a shallow, unconfined, alluvial aquifer with radar and seismic methods at the Boise Hydrogeophysical Research Site (abs.): Geological Society of America Annual Meeting, October 25-29, 1999, Denver, CO, Abstracts with Programs, v. 31, no. 7, p. A144.

Johnson, T.C., Barrash, W., and Clemo, T., 2002, Modeling well-bore skin effects at pumping and observations wells under variable pumping rate (abs.): Fall AGU Meeting, December 6-10, 2002, San Francisco, CA, EOS, v. 83, no. 47, p. F453-F454.

Leven, C., Barrash, W., Hyndman, D.W., and Johnson, T.C., 2002, Modeling a combined tracer and time-lapse radar imaging test in the heterogeneous fluvial aquifer at the Boise Hydrogeophysical Research Site (abs.): Fall AGU Meeting, December 6-10, 2002, San Francisco, CA, EOS, v. 83, no. 47, p. F487.

Moret, G., Buursink, M., Knoll, M.D., and Barrash, W., 2002, Comparing seismic and radar cross-hole tomography to quantify subsurface porosity (abs.): Subsurface Science Symposium, Inland Northwest Research Alliance/Idaho National Engr. and Env. Lab., Boise, ID, Oct. 13-16, 2002.

Oldenborger, G.A., Knoll, M.D., and Barrash, W., 2002, Geostatistical structure of ground-penetrating radar data (abs.): Subsurface Science Symposium, Inland Northwest Research Alliance/Idaho National Engr. and Env. Lab., Boise, ID, Oct. 13-16, 2002.

Peretti, W.R., Knoll, M.D., Barrash, W., Clement, W.P., and Reboulet, E.C., 2000, Radar stratigraphy, lithostratigraphy, and hydrostratigraphy of coarse fluvial deposits at the Boise Hydrogeophysical Research Site (abs.): Geological Society of America Annual Meeting, Nov. 13-16, 2000, Reno, NV, Abstracts with Programs, v. 32, no. 7, p. A410.

Purvance, D.T. and Barrash, W., 2000, The electrical-hydraulic conductivity correlation observed at the Boise Hydrogeophysical Research Site (abs.): Spring AGU Meeting, May 30-June 3, 2000, Washington, DC, EOS, v. 81, no. 19, May 9, 2000 Supplement, p. S212.

Reboulet, E.C. and Barrash, W., 2000, Statistical analysis of grain-size distribution and porosity data from coarse braided-stream deposits at the Boise Hydrogeophysical Research Site (abs.): Geological Society of America Annual Meeting, November 13-16, 2000, Reno, NV, Abstracts with Programs, v. 32, no. 7, p. A410.

Reboulet, E.C. and Barrash, W., 1999, Identification of hydrostratigraphic facies in coarse, unconsolidated, braided-stream deposits at the Boise Hydrogeophysical Research Site (abs.): Geological Society of America Annual Meeting, October 25-29, 1999, Denver, CO, Abstracts with Programs, v. 31, no. 7, p. A350.

### **III.D MANUSCRIPTS SUBMITTED BUT NOT PUBLISHED**

Barrash, W., Clement, W., Clemo, T., and Knoll, M.D., submitted 2002, Porosity as an indicator of subsurface units in coarse unconsolidated fluvial deposits from neutron logs and radar tomography: not sent to review by editor of Geology because manuscript judged inappropriate for this journal.

### **III.E THESES**

Leven, C., 2002, Effects of heterogeneous parameter distributions on hydraulic tests - Analysis and assessment (Ph.D. Dissert.): University of Tübingen, Germany, 88 p.

Moret, G., 2002, Seismic P-wave characterization of the Boise Hydrogeophysical Research Site (M.S. Thesis): Department of Geosciences, Boise State University.

Reboulet, E.C., in preparation for defense in Spring 2003, Lithologic and statistical analysis of core from coarse (cobble and sand) fluvial deposits at the Boise Hydrogeophysical Research Site (M.S. Thesis): Department of Geosciences, Boise State University.

### **III.F TECHNICAL REPORTS**

Barrash, W., Clemo, T., Hyndman, D., Reboulet, E., and Hausrath, E., 2002, Tracer/ Time-Lapse Radar Imaging Test; Design, operation, and preliminary results: DRAFT Report to EPA for Grant X-970085-01-0 and to the U.S. Army Research Office for Grant DAAH04-96-1-0318, Center for Geophysical Investigation of the Shallow Subsurface Technical Report BSU CGISS 02-02, Boise State University, Boise, ID, 120 p.

Clemo, T., 2002, MODFLOW-2000 for cylindrical geometry with internal flow observations and improved water table simulation: Center for Geophysical Investigation of the Shallow Subsurface Technical Report BSU CGISS 02-01, Boise State University, Boise, ID, 29 p.

Hausrath, E.M., Barrash, W., and Reboulet, E.C., 2002, Water sampling and analysis for the Tracer/Time-Lapse Radar Imaging Test at the Boise Hydrogeophysical Research Site: DRAFT Report to EPA for Grant X-970085-01-0 and to the U.S. Army Research Office for Grant DAAH04-96-1-0318, Center for Geophysical Investigation of the Shallow Subsurface Technical Report BSU CGISS 02-03, Boise State University, Boise, ID, 86 p.

Huang, K., Clemo, T., and Barrash, W., 1998, Program developments for modeling groundwater flow in 3D heterogeneous aquifers with MODFLOW and MODFLOWP: Report to U.S. Army Research Office for Grant DAAH04-94-G-0271, Center for Geophysical Investigation of the Shallow Subsurface Technical Report BSU CGISS 97-02, Boise State University, Boise, ID, 31 p.

Leven, C., in prep., Application of the concept of sensitivity coefficients at the Boise Hydrogeophysical Research Site: University of Tuebingen, Center of Applied Geosciences, [unpubl.] Technical Report, 39 p.

Michaels, P., 2002, Basic seismic utilities user's guide, software for engineering geophysics: Center for Geophysical Investigation of the Shallow Subsurface Technical Report, Boise State University, Boise, ID, 81 p.

#### **IV. SCIENTIFIC PERSONNEL (over full period of this project)**

##### **IV.A Faculty Researchers at Boise State University**

Warren Barrash, Ph.D., Research Professor, Center for Geophysical Investigation of the Shallow Subsurface (CGISS) and Department of Geosciences, Boise State University

William Clement, Ph.D., Assistant Research Professor, Center for Geophysical Investigation of the Shallow Subsurface (CGISS), Boise State University

Tom Clemo, Ph.D., Assistant Research Professor, Center for Geophysical Investigation of the Shallow Subsurface (CGISS), Boise State University

Paul Donaldson, Ph.D., Director, Center for Geophysical Investigation of the Shallow Subsurface (CGISS) and Professor, Department of Geosciences, Boise State University

Michael D. Knoll, Ph.D., Research Professor, Center for Geophysical Investigation of the Shallow Subsurface (CGISS) and Department of Geosciences, Boise State University

Paul Michaels, Ph.D., Associate Professor, Department of Geosciences, Boise State University

John Pelton, Ph.D., Dean of the Graduate College and Professor, Department of Geosciences, Boise State University

##### **IV.B Post-Doctoral Scholars**

Kang-Le Huang, Ph.D., Department of Geosciences and Center for Geophysical Investigation of the Shallow Subsurface (CGISS), Boise State University (1996-1997)

Carsten Leven, Ph.D., Department of Geosciences and Center for Geophysical Investigation of the Shallow Subsurface (CGISS), Boise State University (2002-2003)

Jens Tronicke, Ph.D., Post-doctoral scholar from Department of Geophysics, ETH, Switzerland on academic exchange at Boise State University (2002)

##### **IV.C Collaborating Scientists at other Institutions**

Al Cunningham, Ph.D., Montana State University

Robin Gerlach, Ph.D., Montana State University

**Klaus Holliger, Ph.D., ETH, Switzerland**

**David W. Hyndman, Ph.D., Michigan State University**

**Michael Lehman, Ph.D., Idaho National Engineering and Environmental Laboratory**

**Ernie Majer, Ph.D., Lawrence Berkeley National Laboratory**

**Jonathan Mwenifumbo, Ph.D., Geological Survey of Canada**

**John Peterson, Lawrence Berkeley National Laboratory**

**David Purvance, Ph.D., University of Nevada-Reno and HydrOhm Consulting**

**Albane Saintenoy, Ph.D., Colorado School of Mines**

**John Scales, Ph.D., Colorado School of Mines**

**IV.D Graduate Students supported by and/or working with data from this project:**

**Marc Buursink, Ph.D. Candidate (Geophysics), Department of Geosciences and Center for Geophysical Investigation of the Shallow Subsurface (CGISS), Boise State University**

**Jessica Fox, M.S. Candidate (Geology), Department of Geosciences and Center for Geophysical Investigation of the Shallow Subsurface (CGISS), Boise State University**

**Sarah Goldstein, M.S. Candidate (Geophysics), Department of Geosciences and Center for Geophysical Investigation of the Shallow Subsurface (CGISS), Boise State University**

**Clint Hughes, M.S. Candidate (Geology), Department of Geosciences and Center for Geophysical Investigation of the Shallow Subsurface (CGISS), Boise State University**

**Tim Johnson, Ph.D. Candidate (Geophysics), Department of Geosciences and Center for Geophysical Investigation of the Shallow Subsurface (CGISS), Boise State University**

**Carsten Leven, Ph.D. candidate (Applied Geology), University of Tübingen, Germany - on academic exchange at Boise State University in 2001 and conducted part of his dissertation research at the Boise Hydrogeophysical Research Site**

**James McMIndes, M.S. Candidate (Geology-withdrew in 2001), Department of Geosciences and Center for Geophysical Investigation of the Shallow Subsurface (CGISS), Boise State University**

**Geoff Moret, M.S., (Geophysics-Completed in 2002), Department of Geosciences and Center for Geophysical Investigation of the Shallow Subsurface (CGISS), Boise State University**

**Greg Oldenborger, Ph.D. Candidate (Geophysics), Department of Geosciences and Center for Geophysical Investigation of the Shallow Subsurface (CGISS), Boise State University**

**William Peretti, M.S. Candidate (Geophysics), Department of Geosciences and Center for Geophysical Investigation of the Shallow Subsurface (CGISS), Boise State University**

**Edward Reboulet, M.S. Candidate (Geology), Department of Geosciences and Center for Geophysical Investigation of the Shallow Subsurface (CGISS), Boise State University**

**IV.E Other Students**

**In addition, Boise State University undergraduate students (Jason Broome, Aaron Marshall, Robert McAfee, James Nelson, Mike Procsal, J.D. Spalding), and undergraduates, recent graduates, and graduate students from other universities (Frances Clark [Boston University], Alex Gret [Colorado School of Mines], Elisabeth Hausrath [Brown University], Linda Kenoyer [University of Washington], Whitney Trainor [Colorado School of Mines]) have been involved with geophysical and hydrologic field and laboratory experiments associated with this project.**